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(54) Title: INTERLEUKIN-1 RECEPTOR-ASSOCIATED PROTEIN KINASE AND ASSAYS

## (57) Abstract

The invention relates to human Interleukin-1 Receptor-Associated Protein Kinases (IRAKs), nucleic acids which encode IRAKs and hybridization probes and primers capable of hybridizing with IRAK genes and methods of using the subject compositions; in particular, methods such as IRAK-based in vitro binding assays and phosphorylation assays for screening chemical libraries for lead compounds for pharmacological agents.

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*Interleukin-1 Receptor-Associated Protein  
Kinase and Assays*

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation application under 35 USC  
5 120 of USSN 08/494,006 filed 23 June 1985.

INTRODUCTION

Field of the Invention

The field of this invention is a human interleukin receptor associated kinase and its use in drug screening.

10 Background

The cytokine interleukin-1 (IL-1) is a key mediator in the inflammatory response (for reviews, see Refs. 1-3). The importance of IL-1 in inflammation has been demonstrated by the ability of the highly specific IL-1 receptor antagonist protein to relieve inflammatory conditions (for review, see  
15 Refs. 1, 4). Many of the proinflammatory effects of IL-1, such as the upregulation of cell adhesion molecules on vascular endothelia, are exerted at the level of transcriptional regulation. The transcriptional activation  
20 by IL-1 of cell adhesion molecules and other genes involved in the inflammatory response appears to be mediated largely by NF- $\kappa$ B (5-8). In response to IL-1, the NF- $\kappa$ B inhibitory factor I $\kappa$ B is degraded and NF- $\kappa$ B is released from its inactive cytoplasmic state to localize within the nucleus  
25 where it binds DNA and activates transcription (9,10).

Elucidation of the IL-1 signal transduction pathway leading to NF- $\kappa$ B activation would provide valuable insight into mechanisms to alleviate inflammation. In particular, components of this pathway would provide valuable targets for automated, cost-effective, high throughput drug screening and hence would have immediate application in a broad range of domestic and international pharmaceutical and biotechnology drug development programs.

Two cell surface IL-1 receptors, type I (IL-1RI) and type II (IL-1RII), have been identified and molecularly cloned (11, 12). Both receptors have a single transmembrane domain, and an IgG-like extracellular domain. The IL-1RII is found predominantly in B-cells, contains a cytoplasmic domain of only 29 amino acids, and may not play a direct role in intracellular signal transduction (for review, see Ref. 13). The human IL-1RI is found on most cell types and contains 552 amino acids in its mature form. Its cytoplasmic domain of 212 amino acids is required for signaling activity (14-17), but has no significant homology with protein kinases or any other mammalian factors involved in signal transduction. The cytoplasmic domain of IL-1RI does share significant sequence homology with the *Drosophila* transmembrane protein Toll that is involved in dorsal-ventral patterning (18). This homology may be functionally significant since other components of the *Drosophila* dorsal-ventral patterning pathway, Dorsal and Cactus, are homologous with NF- $\kappa$ B and I $\kappa$ B, respectively (19). Also, mutation of the amino acids that are conserved between IL-1RI and Toll inactivates IL-1RI signaling in T cells (15).

### 30 Relevant Literature

Martin et al. (27) report the existence of a mouse IL-1-dependent protein kinase activity co-precipitating with IL-1RI and specific for an endogenous 60 kD substrate. Heguy et al. (15) disclose amino acids conserved in IL-1RI and the *Drosophila* Toll protein that are essential for signal transduction.

## SUMMARY OF THE INVENTION

The invention provides methods and compositions relating to a class of Interleukin-1 Receptor type I-Associated Protein Kinases (IRAK). Native full-length human  
5 IRAKs migrate in SDS polyacrylamide gel electrophoresis at an apparent molecular weight of approximately 100 kD. The compositions include nucleic acids which encode IRAKs and hybridization probes and primers capable of hybridizing with the IRAK genes.

10 The invention includes methods for screening chemical libraries for lead compounds for a pharmacological agent useful in the diagnosis or treatment of disease associated an IRAK activity or an IRAK-dependent signal transduction. In one embodiment, the methods involve (1) forming a mixture  
15 comprising an IRAK, a natural intracellular IRAK substrate or binding target such as the Interleukin-1 receptor, and a candidate pharmacological agent; (2) incubating the mixture under conditions whereby, but for the presence of said candidate pharmacological agent, said IRAK selectively  
20 phosphorylates said substrate or binds said binding target; and (3) detecting the presence or absence of specific phosphorylation of said substrate by said IRAK or phosphorylation or binding of said IRAK to said binding target, wherein the absence of said selective binding  
25 indicates that said candidate pharmacological agent is a lead compound for a pharmacological agent capable of disrupting IRAK function.

## DETAILED DESCRIPTION OF THE INVENTION

The nucleotide sequence of a natural cDNA encoding  
30 human IRAK-1 is shown as SEQUENCE ID NO:1 and the full conceptual translate is shown as SEQUENCE ID NO:2. The IRAKs of the invention include natural derivatives of the IRAK gene and gene product. For example, IRAK-2 is encoded by a derivative of the IRAK-1 cDNA where the coding region  
35 encompassing nucleotides 1514-1552 is deleted. Similarly,

IRAK-3 is a derivative of IRAK-1 where the coding region encompassing nucleotides 1514-1558 is deleted.

The disclosed IRAKs include incomplete translates and deletion mutants of these cDNA sequences and deletion mutants, which translates or deletion mutants have IRAK-specific function such as the kinase activity described herein or IRAK self-association function. For example, the domain bound by residues 212 (Phe) through 523 (Ala) of SEQUENCE ID NO:2 defines an active kinase domain which may be used, independently or joined to other domains, in the subject methods. Similarly, the domain defined by the N-terminal 120 residues of SEQUENCE ID NO:2 defines an IRAK self-association domain. This domain finds use in methods involving higher order IRAK complexes which provide an important means of IRAK regulation. Hence, this domain may be used independently as a regulator or IRAK activity, as a reagent in an IRAK complex formation assay, etc.

The claimed IRAK proteins are isolated, partially pure or pure and are typically recombinantly produced. An "isolated" protein for example, is unaccompanied by at least some of the material with which it is associated in its natural state and constitutes at least about 0.5%, preferably at least about 2%, and more preferably at least about 5% by weight of the total protein in a given sample; a partially pure protein constitutes at least about 10%, preferably at least about 30%, and more preferably at least about 60% by weight of the total protein in a given sample; and a pure protein constitutes at least about 70%, preferably at least about 90%, and more preferably at least about 95% by weight of the total protein in a given sample. A wide variety of molecular and biochemical methods are available for generating and expressing the subject compositions, see e.g. Molecular Cloning, A Laboratory Manual (Sambrook, et al. Cold Spring Harbor Laboratory), Current Protocols in Molecular Biology (Eds. Ausubel, et al., Greene Publ. Assoc., Wiley-Interscience, NY) or that are otherwise known in the art..

The invention provides IRAK-specific binding agents including substrates, natural intracellular binding targets, etc. and methods of identifying and making such agents, and their use in diagnosis, therapy and pharmaceutical development. For example, IRAK-specific agents are useful in a variety of diagnostic and therapeutic applications, especially where disease or disease prognosis is associated with improper utilization of a pathway involving an IRAK, e.g. IL-1 receptor activation. Novel IRAK-specific binding agents include IRAK-specific antibodies and other natural intracellular binding agents identified with assays such as one- and two-hybrid screens, non-natural intracellular binding agents identified in screens of chemical libraries, etc. Agents of particular interest modulate IRAK function, e.g. IRAK antagonists.

Generally, IRAK-specificity of the binding agent is shown by kinase activity (i.e. the agent demonstrates activity of an IRAK substrate, agonist, antagonist, etc.) or binding equilibrium constants (usually at least about  $10^7 \text{ M}^{-1}$ , preferably at least about  $10^8 \text{ M}^{-1}$ , more preferably at least about  $10^9 \text{ M}^{-1}$ ). A wide variety of cell-based and cell-free assays may be used to demonstrate IRAK-specific binding; preferred are rapid in vitro, cell-free assays such as mediating or inhibiting IRAK-protein (e.g. IRAK-IL-1 RI) binding, phosphorylation assays, immunoassays, etc.

The invention also provides nucleic acids encoding the subject proteins, which nucleic acids may be part of IRAK-expression vectors and may be incorporated into recombinant cells for expression and screening, transgenic animals for functional studies (e.g. the efficacy of candidate drugs for disease associated with expression of an IRAK), etc., and nucleic acid hybridization probes and replication/amplification primers having an IRAK cDNA specific sequence contained in SEQUENCE ID NO:1. Nucleic acids encoding IRAKs are isolated from eukaryotic cells, preferably human cells, by screening cDNA libraries with probes or PCR primers derived from the disclosed IRAK cDNAs. In addition, the invention provides IRAK gene homologs

sharing sufficient sequence similarity with that of the disclosed IRAK cDNAs to effect hybridization. Such IRAK cDNA homologs are capable of hybridizing to the IRAK-encoding nucleic acid defined by SEQUENCE ID NO: 1 under low stringency conditions, e.g. a hybridization buffer comprising 0% formamide in 0.9 M saline/0.09 M sodium citrate (SSC) buffer at a temperature of 37°C and remaining bound when subject to washing at 42°C with the SSC buffer at 37°C; or 30% formamide in 5 x SSPE (0.18 M NaCl, 0.01 M NaPO<sub>4</sub>, pH7.7, 0.001 M EDTA) buffer at a temperature of 42°C and remaining bound when subject to washing at 42°C with the 0.2 x SSPE. Preferred nucleic acids will hybridize under moderately stringent conditions, e.g. a hybridization buffer comprising 20% formamide in 0.9 M saline/0.09 M sodium citrate (SSC) buffer at a temperature of 42°C and remaining bound when subject to washing at 42°C with 2 X SSC buffer at 42°C; or a hybridization buffer comprising 50% formamide in 5 x SSPE buffer at a temperature of 42°C and remain bound when subject to washing at 42°C with 0.2 x SSPE buffer at 42°C. More preferred nucleic acids encode kinases comprising kinase domains with at least about 25%, preferably at least about 50% pair-wise identity to a disclosed IRAK kinase domain.

The subject nucleic acids are recombinant, meaning they comprise a sequence joined to a nucleotide other than that which it is joined to on a natural chromosome and are often isolated, i.e. constitute at least about 0.5%, preferably at least about 5% by weight of total nucleic acid present in a given fraction. The recombinant nucleic acids may be contained within vectors, cells or organisms. The subject nucleic acids find a wide variety of applications including use as translatable transcripts, hybridization probes, PCR primers, therapeutic nucleic acids, etc.; use in detecting the presence of IRAK genes and gene transcripts, in detecting or amplifying nucleic acids encoding additional IRAK homologs and structural analogs, and in gene therapy applications.

The invention provides efficient methods of identifying pharmacological agents or lead compounds for agents active at the level of an IRAK modulatable cellular function, particularly IRAK mediated IL-1 signal transduction, especially in inflammation. Generally, these screening methods involve assaying for compounds which interfere with an IRAK activity such as kinase activity or IL-1 receptor I binding. The methods are amenable to automated, cost-effective high throughput screening of chemical libraries for lead compounds. Identified reagents find use in the pharmaceutical industries for animal and human trials; for example, the reagents may be derivatized and rescreened in in vitro and in vivo assays to optimize activity and minimize toxicity for pharmaceutical development. Target therapeutic indications are limited only in that the target cellular function be subject to modulation, usually inhibition, by disruption of the formation of a complex comprising an IRAK and one or more natural IRAK intracellular binding targets including substrates. Target indications may include infection, genetic disease, cell growth and regulatory disfunction, such as neoplasia, inflammation, hypersensitivity, etc.

A wide variety of assays for binding agents are provided including labeled in vitro kinase assays, protein-protein binding assays, immunoassays, cell based assays, etc. The IRAK compositions used the methods are usually added in an isolated, partially pure or pure form and are typically recombinantly produced. The IRAK may be part of a fusion product with another peptide or polypeptide, e.g. a polypeptide that is capable of providing or enhancing protein-protein binding, stability under assay conditions (e.g. a tag for detection or anchoring), etc. The assay mixtures comprise a natural intracellular IRAK binding target including substrates, such as the C-terminus IL-1 RI or, in the case of an autophosphorylation assay, the IRAK itself can function as the binding target. An IRAK derived pseudosubstrate may be used or modified (e.g. A to S/T substitutions) to generate effective substrates for use in

the subject kinase assays. The use of serine/threonine kinase pseudosubstrate peptides and the generation of substrate peptides therefrom are well known in the art. While native binding targets may be used, it is frequently preferred to use portions (e.g. peptides, nucleic acid fragments) thereof so long as the portion provides binding affinity and avidity to the subject IRAK conveniently measurable in the assay. The assay mixture also comprises a candidate pharmacological agent. Candidate agents encompass numerous chemical classes, though typically they are organic compounds; preferably small organic compounds and are obtained from a wide variety of sources including libraries of synthetic or natural compounds. A variety of other reagents may also be included in the mixture. These include reagents like salts, buffers, neutral proteins, e.g. albumin, detergents, etc. which may be used to facilitate optimal binding and/or reduce non-specific or background interactions, etc. Also, reagents that otherwise improve the efficiency of the assay, such as protease inhibitors, nuclease inhibitors, antimicrobial agents, etc. may be used.

The resultant mixture is incubated under conditions whereby, but for the presence of the candidate pharmacological agent, the IRAK specifically binds the cellular binding target, portion or analog. The mixture components can be added in any order that provides for the requisite bindings. Incubations may be performed at any temperature which facilitates optimal binding, typically between 4 and 40°C, more commonly between 15° and 40°C. Incubation periods are likewise selected for optimal binding but also minimized to facilitate rapid, high-throughput screening, and are typically between .1 and 10 hours, preferably less than 5 hours, more preferably less than 2 hours.

After incubation, the presence or absence of specific binding between the IRAK and one or more binding targets is detected by any convenient way. For cell-free binding type assays, a separation step is often used to separate bound from unbound components. Separation may be effected by

precipitation (e.g. TCA precipitation, immunoprecipitation, etc.), immobilization (e.g. on a solid substrate), etc., followed by washing by, for examples, membrane filtration (e.g. Whatman's P-81 ion exchange paper, Polyfiltronic's hydrophobic GFC membrane, etc.), gel chromatography (e.g. gel filtration, affinity, etc.). For kinase assays, binding is detected by a change in the kinase activity of the IRAK.

Detection may be effected in any convenient way. For cell-free binding assays, one of the components usually comprises or is coupled to a label. A wide variety of labels may be employed - essentially any label that provides for detection of bound protein. The label may provide for direct detection as radioactivity, luminescence, optical or electron density, etc. or indirect detection such as an epitope tag, an enzyme, etc. A variety of methods may be used to detect the label depending on the nature of the label and other assay components. For example, the label may be detected bound to the solid substrate or a portion of the bound complex containing the label may be separated from the solid substrate, and thereafter the label detected. Labels may be directly detected through optical or electron density, radiative emissions, nonradiative energy transfers, etc. or indirectly detected with antibody conjugates, etc. For example, in the case of radioactive labels, emissions may be detected directly, e.g. with particle counters or indirectly, e.g. with scintillation cocktails and counters.

The following experiments and examples are offered by way of illustration and not by way of limitation.

#### EXPERIMENTAL

Based on its lack of homology with any known mammalian signal transducers, it is likely that the intracellular region of IL-1RI interacts with other factors to transduce IL-1 signals. We sought to delineate a receptor domain that interacts with such factors by examining the ability of IL-1RI mutants to activate NF- $\kappa$ B. To measure NF- $\kappa$ B activation we utilized an assay in which expression vectors for IL-1RI

mutants were cotransfected with an E-selectin promoter-luciferase reporter plasmid into the human 293 cell line. Stimulation of E-selectin transcription by IL-1 is known to occur primarily through the activation of NF- $\kappa$ B (24, 25).  
5 Luciferase activity in transiently transfected 293 cells was determined in the presence or absence of IL-1 stimulation. In the absence of transfected receptor, IL-1 (1 ng/ml) induced a low level of transcriptional activation through endogenous IL-1RI. However, a large increase in IL-1  
10 dependent transcriptional activation was observed in cells transiently transfected with wild type IL-1RI. This result demonstrates that the majority of reporter activity in transiently transfected cells is signaled by transfected IL-1RI, and validates the use of this system for the analysis  
15 of IL-1RI mutants.

Five different C-terminal truncation mutants of IL-1RI were examined for their ability to activate the E-selectin reporter in response to IL-1. Removal of 20, 25 or 31 amino acids from the C-terminus did not appreciably affect the  
20 ability of IL-1RI to activate NF- $\kappa$ B. Deletion of 45 or 75 C-terminal amino acids eliminated the ability of IL-1RI to activate NF- $\kappa$ B. Therefore, the region defined by the -31 and -45 deletions (residues 508-521) includes sequences required for the activation of NF- $\kappa$ B by IL-1. Furthermore,  
25 the -45 and -75 deletion mutants behaved as dominant negative mutations and blocked the ability of the endogenous IL-1RI to activate NF- $\kappa$ B.

Since amino acids 508 to 521 of IL-1RI appear necessary for signal transduction, this region was examined more  
30 closely by constructing receptors with sets of three amino acids mutated to alanine. These mutants, which include 510-512A, 513-515A, and 518-520A, were analyzed in the NF- $\kappa$ B reporter assay for their ability to activate NF- $\kappa$ B. By this analysis the 510-512A mutant is active, while the 513-515A  
35 and 518-520A mutants are inactive. Amino acids 510, 511, and 512 of the IL-1RI are not conserved in Toll, while conserved amino acids are present in both the 513-515 and 518-520 regions. The requirement of these conserved

residues for IL-1RI function may indicate that these amino acids directly contact signaling molecules or are critical to overall receptor structure.

We next performed immunoprecipitation experiments to identify IL-1RI-associated signaling molecules. Immunoprecipitation of metabolically <sup>35</sup>S-labeled IL-1RI from transiently transfected 293 cells reveals that the receptor is expressed at high levels and can be specifically immunoprecipitated with polyclonal antisera directed against the IL-1RI extracellular domain. In agreement with previously published results (20), FACS analysis of 293 cells transiently transfected with IL-1RI indicated that a large percentage (~40%) of the cell population express receptor. The addition of IL-1 to cells prior to cell lysis had no effect on the ability of the antisera to immunoprecipitate IL-1RI.

To determine whether a protein kinase associates with IL-1RI, the receptor was immunoprecipitated from transiently transfected 293 cells and examined by an *in vitro* kinase assay. An IL-1-inducible protein kinase activity was observed that specifically associated with IL-1RI. We have termed this activity IRAK (IL-1RI Associated Kinase). The major target of the IRAK in this reaction is an endogenous substrate of approximately 100 kDa. The specificity of the receptor-kinase interaction is supported by the absence of activity in the preimmune precipitate, and by the ability of an IL-1RI-IgG fusion protein to compete away the kinase activity when added to the immunoprecipitation. Kinase activation occurred rapidly, reaching an optimum within two minutes of exposure of cells to IL-1, suggesting that activation of the kinase occurs proximally to the IL-1 receptor.

If IRAK is involved in NF- $\kappa$ B activation, then the activity of the kinase in immunoprecipitates of mutated receptor should correlate with *in vivo* activation of the E-selectin reporter by mutated receptors. The C-terminal deletions mutants of IL-1RI were transiently expressed in 293 cells, receptor was immunoprecipitated, and examined for

associated IL-1 inducible kinase activity. In the absence of transfected receptor, 293 cells display low but detectable levels of IRAK activity. All three C-terminal deletion mutants (-20, -25, -31) that can activate NF- $\kappa$ B display associated kinase activity that is indistinguishable from that associated with intact IL-1RI. IRAK activity does not coprecipitate with the -45 deletion mutant that was unable to activate NF- $\kappa$ B. Thus, there is a direct correlation between the association of active IRAK with IL-1RI and the ability of IL-1 to activate NF- $\kappa$ B.

To further examine the connection between NF- $\kappa$ B activation and IRAK kinase activity, the triple alanine scan mutants of IL-1RI were examined by the coimmunoprecipitation assay following transfection into 293 cells. IRAK activity was observed with the 510-512A mutant, but not with the 513-515 Ala or 518-520 Ala mutants. Once again there was a direct correlation between the ability of an IL-1RI mutant to interact with IRAK and to induce NF- $\kappa$ B activation.

In order to purify pp100, we stably transfected 293 cells with IL-1RI expression plasmid. The 293/IL-1RI cells express IL-1RI at a level at least two orders of magnitude greater than that of parental 293 cells as shown by FACS analyses. The cells were grown in suspension and treated briefly with IL-1 before harvest and extract preparation. pp100 was purified from extracts prepared from 100 liters of cells by a large scale immunoprecipitation using rabbit antibodies to the extracellular domain of IL-1RI. To follow pp100, immunoprecipitants were subjected to an in vitro kinase reaction in the presence of  $\gamma^{32}\text{P}$ -ATP. pp100 eluted from the IL-1RI immunocomplex was further purified by Q sepharose column chromatography. Protein fractions containing radiolabeled pp100 were subjected to two-dimensional gel electrophoresis and blotted to polyvinylidene difluoride (PVDF) membrane. pp100 (about 0.4  $\mu\text{g}$ ) was identified by autoradiography and digested with lysine-C and trypsin. The resulting peptides were fractionated by capillary high-performance liquid chromatography. Amino acid sequences of 10 polypeptides

were obtained, which were used to design degenerate oligonucleotides as primers for polymerase chain reaction (PCR). A DNA fragment of 356 nucleotides was amplified from cDNA prepared using mRNA from 293 cells. This DNA fragment  
5 encodes the peptide used to design the PCR primers as well as three other sequenced peptides. Using this DNA fragment as a probe, we isolated corresponding cDNA clones from a human teratocarcinoma cDNA library. The longest clone obtained is 3.5 kilobase pair in length (SEQUENCE ID NO:1)  
10 and encodes a protein of 699 amino acids (SEQUENCE ID NO:2). An in-frame stop codon was located 36 nucleotides upstream from the first methionine, indicating that the clone encodes a full length protein.

Sequence analysis of the protein revealed a region  
15 similar to the catalytic domain of kinases. Eleven subdomains and 15 invariable amino acids indicative of a protein kinase are present. Search of the NCBI BLAST database with the kinase domain sequence revealed similarity between pp100 and several serine/threonine kinases. The  
20 kinase of animal origin that shared highest sequence similarity with pp100 is drosophila Pelle which is 33% identical in the 298 amino acid kinase domain. The research also revealed homology between pp100 and few plant kinases of unknown functions and the plant Tpo gene which confers  
25 resistance to bacteria *Pseudomonas syringae* pv. tomato in Tomato.

#### Methods I: Identification of IRAK Activity.

*Plasmid Construction and Antiserum Preparation* - The human IL-1RI cDNA was cloned into pRK5 (20) to give the  
30 plasmid pRK-IL-1RI in which expression is under the control of the cytomegalovirus immediate early promoter-enhancer. Expression plasmids for the C-terminal deletion mutants of IL-1 receptor were generated from pRK-IL-1RI by introducing stop codons into the IL-1RI coding region by polymerase  
35 chain reaction (PCR). The internal triple mutants were made by a procedure involving two rounds of PCR. The first round of PCR generated overlapping fragments with the corresponding mutations in the center of the overlapped

region. The two fragments were joined by a second round of PCR. The sequences of all constructs were confirmed by DNA sequencing. To prepare antiserum to the extracellular domain of the IL-1RI, a fusion protein consisting of the mature IL-1RI extracellular domain fused to human IgG as described (22), was expressed transiently in 293 cells. Cell culture medium containing the chimeric protein was harvested on 3 and 7 days after transfection. The IL-1RI-IgG fusion protein was purified by protein A-agarose chromatography and used to immunize rabbits by BABCo (Richmond, CA).

*Cell culture, transfection, cell extract preparation and metabolic labeling* - Human embryonic kidney 293 cells were grown in DMEM medium supplemented with 10% fetal calf serum, 100 mg/ml penicillin G and 100 mg/ml streptomycin (Gibco). To assay receptor function, cells were seeded in 6-well dishes at 30-50% confluence. Transfections were carried out the following day with the various expression plasmids by the calcium phosphate precipitation method (23). 36 hours later, human recombinant IL-1 $\beta$  (Genentech) was added to the medium at final concentration of 1 ng/ml. The cells were harvested 6 hours later and assayed for luciferase activity using Promega reagents.  $\beta$ -galactosidase activity was determined using chemiluminescent reagents (Tropix, Inc.) and used to normalize luciferase activities. Extracts for immunoprecipitations and in vitro phosphorylation assays were prepared as follows: 293 cells were seeded at 50% density in 100 mm plates and transfected with IL-1RI expression plasmids on the following day. 40 to 48 hours later, IL-1 (20 ng/ml) was added to the media. After incubation at 37°C for the indicated times, media was removed and the plates were chilled on ice immediately. The cells were washed twice with 5 ml of ice-cold phosphate buffered saline (PBS) and scraped off the plates in 5 ml of PBS containing 1 mM EDTA. Cells were pelleted by 1200 x g centrifugation for 3 minutes and suspended in 1 ml of lysis buffer (50 mM HEPES pH 7.6, 250 mM NaCl, 1 mM dithiothreitol (DTT), 1 mM EDTA, 0.1% Tween-20, 10% (v/v) glycerol, 10 mM

b-glycerophosphate, 5 mM p-nitrophenyl phosphate, 1 mM Na orthovanadate, 1 mM benzamidine, 0.4 mM phenylmethylsulfonyl fluoride, 1 mM Na metabisulfite, 10 ug/ml leupeptin and 10 ug/ml aprotinin). After incubation on ice for 20 minutes, the cell debris was pelleted by a 20 minute centrifugation in a microcentrifuge and the supernatants were collected and stored at -70°C. For metabolic labelling, 293 cells were seeded in 150 mm plates and grown to near confluence. The cells were washed twice with 25°C PBS and incubated with DMEM lacking cysteine and methionine at 37°C for 40 minutes before addition of 700 uCi of <sup>35</sup>S cell labelling mix (Amersham). Four hours later, the medium was removed and cells were washed twice with PBS and extracts were prepared as described above.

*Immunoprecipitation and in vitro kinase assays* - For immunoprecipitations, 1 ml of cellular extract was incubated with 20 ml of protein A-agarose slurry (50% v/v) in lysis buffer at 4°C for 2 hours. Protein A beads were pelleted by centrifugation in a microcentrifuge for 10 seconds and 1 ml of rabbit antiserum or preimmune serum was incubated with the precleared supernatant at 4°C for 2-3 hours. The reactions were mixed with 20 ul of the protein A-agarose slurry and incubated for an additional 1 hour. Protein A beads were collected by centrifugation in a microcentrifuge for 10 seconds, and washed 5 times with 1 ml of lysis buffer. The beads were then suspended in 20 ul of kinase buffer containing 20 mM Tris-HCl pH 7.6, 20 mM MgCl<sub>2</sub>, 20 mM β-glycerophosphate, 20 mM p-nitrophenyl phosphate, 1 mM Na orthovanadate, 1mM benzamidine, 0.4 mM PMSF, 1 mM Na metabisulfite, 2 uM cold ATP and 10 uCi [<sup>32</sup>P]γ -ATP. The kinase reactions were allowed to proceed at 30°C for 30 minutes and terminated with 20 ml of SDS sample buffer. After boiling for 3-5 minutes, 20 ml reaction aliquots were separated by 8% SDS-PAGE. Radiolabeled proteins were visualized by autoradiography.

Methods II. Purification and Cloning of IRAK.

*Cell Culture:* 293 cells were cultured in Dulbecco's Modification of Eagle's Medium with 4.5 gram/ml glucose and

L-glutamine (Mediatech) supplemented with 10% fetal bovine serum, 100 ug/ml streptomycin and 100 ug/ml penicillin. To make 293 cells overproducing the human IL-1RI, 293 cells were seeded on 100 mm plates at 30% density and were  
5 transfected on the following day with 10 mg IL-1RI expression plasmid (supra) and 1 mg pNeo by calcium phosphate precipitation. Stably transfected cells were selected with culture medium containing 500  $\mu$ g/ml of G418 (Gibco). Ten individual colonies were cloned and expanded.  
10 The expression IL-RI on the cell surface was monitored by FACS using antibody to the extracellular domain of the IL-1RI. Four clones which showed the desirable IL-1RI expression and growth behavior were transferred to suspension culture in CO<sub>2</sub>-independent Minimum Essential  
15 Medium (MEM, Mediatech) supplemented 10% fetal bovine serum, 4.5 g/ml glucose, 1 mM sodium pyruvate (Gibco), 100 ug/ml streptomycin and 100 ug/ml penicillin.

*Extract Preparation:* Cells from suspension culture (100 liters) were pelleted in a Sorvall GS-3 rotor at 2500 RPM  
20 for 5 minutes and re-suspended in 5 liters of pre-warmed serum-free MEM medium. The cells were incubated with 200 ng/ml recombinant human IL-1 $\beta$  (Genentech) at 37°C for 3 minutes and pelleted by centrifugation at 4°C. All of the following steps were performed at 4°C. The cells were  
25 suspended in 5 pelleted-cell-volumes of buffer containing 50 mM Hepes pH 7.9, 250 mM NaCl, 5 mM dithiothreitol (DTT), 1 mM EDTA, 0.1% NP-40, 10% (v/v) glycerol, 20 mM b glycerophosphate, 5 mM p-nitrophenyl phosphate, 1 mM Na orthovanadate, 1 mM benzamidine, 0.4 mM phenylmethylsulfonyl  
30 fluoride (PMSF), 1 mM Na metabisulfite, 10 ug/ml leupeptin and 10 ug/ml aprotinin. After incubation on ice for 30 minutes with occasional rocking, the cell lysate was centrifuged in a Sorvall H6000A rotor at 4000 RMP for 10 minutes. The supernatants were collected and centrifuged in  
35 a Beckman 45 TI rotor at 40,000 RPM for 2 hours. The supernatants were aliquoted and stored at -70°C.

*Purification of pp100:* the extracts were thawed and spun in a Beckman 45 TI at 40,000 RPM for 2 hours. The

supernatants were incubated with 40 mg of rabbit IgG against the extracellular domain of the IL-1R at 4°C for 2 hours with rocking. 25 ml of protein A sepharose CL4B (Pharmacia) were mixed with the extracts and the incubation continued for another 2 hours. The protein A beads were collected in a column and washed with 250 ml of washing buffer #1 containing 50 mM Hepes pH 7.9, 250 mM NaCl, 5 mM dithiothreitol (DTT), 1 mM EDTA, 0.1% NP-40, 20 mM  $\beta$  glycerophosphate, 1 mM Na orthovanadate, 1 mM benzamidine, 0.4 mM phenylmethylsulfonyl fluoride (PMSF), 1 mM Na metabisulfite. The beads were then suspended in 50 ml kinase buffer containing 20 mM Tris-HCl pH 7.6, 20 mM  $MgCl_2$ , 20 mM  $\beta$  glycerophosphate, 20 mM p-nitrophenylphosphate, 1 mM EDTA, 1 mM Na orthovanadate, 1 mM benzamidine, 0.4 mM PMSF, 1 mM Na metabisulfite, 5 mM cold ATP and 100 mCi [ $^{32}P$ ]g -ATP and incubated at 30°C for 15 minutes. The kinase reaction was chased with 100 mM of unlabeled ATP for an additional 15 minutes. Protein A beads were collected in an empty column and washed with 150 ml of washing buffer #2 containing 150 ml of buffer consisted of 50 mM Hepes, pH 7.9, 1 M NaCl, 5 mM DTT, 1 mM EDTA and 0.1% NP40, then 150 ml of washing buffer #3 consisting of 50 mM Hepes, pH 7.9, 100 mM NaCl, 2 M urea, 5 mM DTT, 1 mM EDTA and 0.1% NP40. The proteins were then eluted with 50 ml of elution buffer containing 50mM Hepes, pH 7.9, 100 mM NaCl, 5 mM DTT, 1 mM EDTA, 0.1% NP-40 and 7 M urea at 4°C overnight with rocking. The eluted materials were loaded on a 0.5 ml Q Sepharose column equilibrated in the elution buffer. The column was washed extensively with the elution buffer before bound proteins were eluted with buffer containing 0.5 M NaCl. The high salt eluate was concentrated in a Centricon 50 (Microcon) to 50  $\mu$ l, diluted with 1 ml isoelectric focusing sample buffer (O'Farrell (1975) J. Biol Chem), concentrated down again to 50  $\mu$ l. The sample was then subjected to two-dimensional gel electrophoresis.

*Two-dimensional gel electrophoresis and micro peptide sequencing:* Isoelectric focusing was used as the first dimensional separation. The preparation and running

conditions were described previously. The pH gradient was created with ampholines pH 5.0-7.0 and pH 3.5-9.5 blended at a ratio of 1:1. 7% acrylamide SDS gel electrophoresis was used as second dimension separation. After the electrophoresis, the proteins were transferred to a polyvinylidenedifluoride membrane (Milipore) and stained with Coomassie blue R-250 in 40% methanol and 10% acetic acid for 30 seconds, followed by a 5 minute de-staining in 40% methanol and 10% acetic acid. The area of membrane containing the pp100 substrate indicated by autoradiography was excised and subjected to peptidase digestion and micro-peptide-sequencing as described (Hou et al. (1994) *Science* 265,1701-1706).

#### Parentetical References

- (1) Dinarello (1991) *Blood* 77:1627-1652; (2) Dinarello and Wolff (1993) *New England J. Med.* 328:106-113; (3) Dinarello (1994) *FASEB J.* 8:1314-1325; (4) Dinarello (1993) *Immunol. Today* 14:260-264; (5) Shirakawa and Mizel (1989) *Molec. Cell Biol.* 9:2424-2430; (6) Osborn et al., (1989) *Proc. Natl. Acad. Sci. USA* 86:2336-2340; (7) Krasnow et al., (1991) *Cytokine* 3:372-379; (8) Collins et al., (1993) *Trends Cardiovasc. Med.* 3:92-97; (9) Liou and Baltimore (1993) *Curr. Opin. in Cell Biol.* 5:477-487; (10) Beg et al., (1993) *Mol. Cell. Biol.* 13:3301-3310; (11) Sims et al., (1988) *Science* 241:585-589; (12) McMahan et al., (1991) *EMBO J.* 10:2821-2832; (13) Colotta et al., (1994) *Immunol. Today* 15:562-566; (14) Curtis et al., (1989) *Proc. Natl. Acad. Sci. USA* 86:3045-3049; (15) Heguy et al., (1992) *J. Biol. Chem.* 267:2605-2609; (16) Kuno et al., (1993) *J. Biol. Chem.* 268:13510-13518; (17) Leung et al., (1994) *J. Biol. Chem.* 269:1579-1582; (18) Hashimoto et al., (1988) *Cell* 52:269-279; (19) Wasserman (1993) *Molec. Biol. of the Cell* 4:767-771; (20) Schall et al., (1990) *Cell* 61:361-370; (21) Schindler and Baichwal (1994) *Mol. Cell. Biol.* 14:5820-5831; (22) Pitti et al., (1994) *Mol. Immunol.* 17:1345-135; (23) Ausubel et al., (1994) *Current Protocols in Molecular Biology* Greene Publishing Associates/Wiley & Sons, New York; (24) Whelan et al., (1991) *Nucleic Acids Res.* 19:2645-2653;

- (25) Montgomery et al., (1991) *Proc. Natl. Acad. Sci. USA* 88:6523-6527; (26) Stylianou et al., (1992) *J. Biol. Chem.* 267:15836-15841; (27) Martin et al., (1994) *Eur. J. Immunol.* 24:1566-1571; and (28) Freshney et al., (1994) *Cell* 78:1039-1049.

## EXAMPLES

## 1. Protocol for IRAK autophosphorylation assay.

## A. Reagents:

- Neutralite Avidin: 20  $\mu$ g/ml in PBS.
- IRAK:  $10^{-8}$  -  $10^{-5}$  M biotinylated IRAK-1 at 20  $\mu$ g/ml in PBS.
- Blocking buffer: 5% BSA, 0.5% Tween 20 in PBS; 1 hour at room temperature.
- Assay Buffer: 100 mM KCl, 20 mM HEPES pH 7.6, 0.25 mM EDTA, 1% glycerol, 0.5% NP-40, 50 mM BME, 1 mg/ml BSA, cocktail of protease inhibitors.
- [ $^{32}$ P] $\gamma$ -ATP 10x stock:  $2 \times 10^{-5}$  M cold ATP with 100  $\mu$ Ci [ $^{32}$ P] $\gamma$ -ATP. Place in the 4°C microfridge during screening.
- Protease inhibitor cocktail (1000X): 10 mg Trypsin Inhibitor (BMB # 109894), 10 mg Aprotinin (BMB # 236624), 25 mg Benzamidine (Sigma # B-6506), 25 mg Leupeptin (BMB # 1017128), 10 mg APMSF (BMB # 917575), and 2mM NaVO<sub>3</sub> (Sigma # S-6508) in 10 ml of PBS.

## B. Preparation of assay plates:

- Coat with 120  $\mu$ l of stock N Avidin per well overnight at 4°C.
- Wash 2 times with 200  $\mu$ l PBS.
- Block with 150  $\mu$ l of blocking buffer.
- Wash 2 times with 200  $\mu$ l PBS.

## C. Assay:

- Add 40  $\mu$ l assay buffer/well.
- Add 40  $\mu$ l biotinylated IRAK (0.1-10 pmoles/40  $\mu$ l in assay buffer)

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- Add 10  $\mu$ l compound or extract.
  - Add 10  $\mu$ l [ $^{32}$ P] $\gamma$ -ATP 10x stock.
  - Shake at 25°C for 15 minutes.
  - Incubate additional 45 minutes at 25°C.
  - 5 - Stop the reaction by washing 4 times with 200  $\mu$ l PBS.
  - Add 150  $\mu$ l scintillation cocktail.
  - Count in Topcount.
- D. Controls for all assays (located on each plate):
- a. Non-specific binding
  - 10 b. cold ATP at 80% inhibition.
2. Protocol for IRAK - IL1RI complex formation assay.
- A. Reagents:
- Neutralite Avidin: 20  $\mu$ g/ml in PBS.
  - Blocking buffer: 5% BSA, 0.5% Tween 20 in PBS; 1 hour
  - 15 at room temperature.
  - Assay Buffer: 100 mM KCl, 20 mM HEPES pH 7.6, 0.25 mM EDTA, 1% glycerol, 0.5% NP-40, 50 mM  $\beta$ -mercaptoethanol, 1 mg/ml BSA, cocktail of protease inhibitors.
  - $^{33}$ P IRAK 10x stock:  $10^{-8}$  -  $10^{-6}$  M "cold" IRAK
  - 20 supplemented with 200,000-250,000 cpm of labeled IRAK (Beckman counter). Place in the 4°C microfridge during screening.
  - Protease inhibitor cocktail (1000X): 10 mg Trypsin Inhibitor (BMB # 109894), 10 mg Aprotinin (BMB # 236624), 25
  - 25 mg Benzamidine (Sigma # B-6506), 25 mg Leupeptin (BMB # 1017128), 10 mg APMSF (BMB # 917575), and 2mM NaVO<sub>3</sub> (Sigma # S-6508) in 10 ml of PBS.
  - IL-1RI:  $10^{-8}$  -  $10^{-5}$  M biotinylated IL-1RI intracellular domain (residues 327-527) in PBS.
- 30 B. Preparation of assay plates:
- Coat with 120  $\mu$ l of stock N-Avidin per well overnight at 4°C.
  - Wash 2 times with 200  $\mu$ l PBS.
  - Block with 150  $\mu$ l of blocking buffer.

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- Wash 2 times with 200  $\mu$ l PBS.

## C. Assay:

- Add 40  $\mu$ l assay buffer/well.
- Add 10  $\mu$ l compound or extract.
- 5     - Add 10  $\mu$ l  $^{33}\text{P}$ -IRAK (20,000-25,000 cpm/0.1-10 pmoles/well =  $10^{-9}$ -  $10^{-7}$  M final concentration).
- Shake at 25°C for 15 minutes.
- Incubate additional 45 minutes at 25°C.
- Add 40  $\mu$ l biotinylated IL-1RI intracellular domain
- 10   (0.1-10 pmoles/40  $\mu$ l in assay buffer)
- Incubate 1 hour at room temperature.
- Stop the reaction by washing 4 times with 200  $\mu$ l PBS.
- Add 150  $\mu$ l scintillation cocktail.
- Count in Topcount.

- 15 D. Controls for all assays (located on each plate):
- a. Non-specific binding
  - b. Soluble (non-biotinylated IL-1RI intracellular domain ) at 80% inhibition.

20 All publications and patent applications cited in this specification are herein incorporated by reference as if each individual publication or patent application were specifically and individually indicated to be incorporated by reference. Although the foregoing invention has been described in some detail by way of illustration and example

25 for purposes of clarity of understanding, it will be readily apparent to those of ordinary skill in the art in light of the teachings of this invention that certain changes and modifications may be made thereto without departing from the spirit or scope of the appended claims.

## SEQUENCE LISTING

## (1) GENERAL INFORMATION:

- (i) APPLICANT: Tularik, Inc.
- (ii) TITLE OF INVENTION: INTERLEUKIN-1 RECEPTOR-ASSOCIATED PROTEIN KINASE AND BINDING ASSAY
- (iii) NUMBER OF SEQUENCES: 2
- (iv) CORRESPONDENCE ADDRESS:
  - (A) ADDRESSEE: FLEHR, HOHBACH, TEST, ALBRITTON & HERBERT
  - (B) STREET: 4 Embarcadero Center, Suite 3400
  - (C) CITY: San Francisco
  - (D) STATE: California
  - (E) COUNTRY: USA
  - (F) ZIP: 94111-4187
- (v) COMPUTER READABLE FORM:
  - (A) MEDIUM TYPE: Floppy disk
  - (B) COMPUTER: IBM PC compatible
  - (C) OPERATING SYSTEM: PC-DOS/MS-DOS
  - (D) SOFTWARE: PatentIn Release #1.0, Version #1.30
- (vi) CURRENT APPLICATION DATA:
  - (A) APPLICATION NUMBER: PCT/US96/
  - (B) FILING DATE: JUNE 5 1996
  - (C) CLASSIFICATION:
- (vii) PRIOR APPLICATION DATA:
  - (A) APPLICATION NUMBER: U.S. Serial No. 08/587,889
  - (B) FILING DATE: JAN 16 1996
  - (C) CLASSIFICATION:
    - WHICH IS A CONTINUATION OF
  - (A) APPLICATION NUMBER: U.S. Serial No. 08/494,006
  - (B) FILING DATE: JUNE 23 1995
  - (C) CLASSIFICATION:
- (viii) ATTORNEY/AGENT INFORMATION:
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  - (C) REFERENCE/DOCKET NUMBER: FP-62191-1
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  - (C) TELEX: 910 277299

## (2) INFORMATION FOR SEQ ID NO:1:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 3590 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: double
  - (D) TOPOLOGY: linear
- (ii) MOLECULE TYPE: cDNA
- (xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

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CGAGCTGCGG CTGTGCGAGC GCTCCGGGCA GCGCACGGCC AGCGTCCTGT GGCCCTGGAT	300
CAACCGCAAC GCCCGTGTGG CCGACCTCGT GCACATCCTC ACGCACCTGC AGCTGCTCCG	360
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AGGGCCTGAG CTCGGCCTGG TTCCAAGCCC TGCTTCCCTG TGGCCTCCAC CGCCATCTCC	600
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CAGCCTCATC CATGGAGACA TCAAGAGTTC CAACGTCCTT CTGGATGAGA GGCTGACACC	1140
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## (2) INFORMATION FOR SEQ ID NO:2:

- (i) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 712 amino acids
  - (B) TYPE: amino acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

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20           25           30

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-25-

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 35 40 45  
 Ile Val Arg Asp Gln Thr Glu Leu Arg Leu Cys Glu Arg Ser Gly Gln  
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 Arg Thr Ala Ser Val Leu Trp Pro Trp Ile Asn Arg Asn Ala Arg Val  
 65 70 75 80  
 Ala Asp Leu Val His Ile Leu Thr His Leu Gln Leu Leu Arg Ala Arg  
 85 90 95  
 Asp Ile Ile Thr Ala Trp His Pro Pro Ala Pro Leu Pro Ser Pro Gly  
 100 105 110  
 Thr Thr Ala Pro Arg Pro Ser Ser Ile Pro Ala Pro Ala Glu Ala Glu  
 115 120 125  
 Ala Trp Ser Pro Arg Lys Leu Pro Ser Ser Ala Ser Thr Phe Leu Ser  
 130 135 140  
 Pro Ala Phe Pro Gly Ser Gln Thr His Ser Gly Pro Glu Leu Gly Leu  
 145 150 155 160  
 Val Pro Ser Pro Ala Ser Leu Trp Pro Pro Pro Pro Ser Pro Ala Pro  
 165 170 175  
 Ser Ser Thr Lys Pro Gly Pro Glu Ser Ser Val Ser Leu Leu Gln Gly  
 180 185 190  
 Ala Arg Pro Ser Pro Phe Cys Trp Pro Leu Cys Glu Ile Ser Arg Gly  
 195 200 205  
 Thr His Asn Phe Ser Glu Glu Leu Lys Ile Gly Glu Gly Gly Phe Gly  
 210 215 220  
 Cys Val Tyr Arg Ala Val Met Arg Asn Thr Val Tyr Ala Val Lys Arg  
 225 230 235 240  
 Leu Lys Glu Asn Ala Asp Leu Glu Trp Thr Ala Val Lys Gln Ser Phe  
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 260 265 270  
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 275 280 285  
 Gly Phe Leu Pro Asn Gly Ser Leu Glu Asp Arg Leu His Cys Gln Thr  
 290 295 300  
 Gln Ala Cys Pro Pro Leu Ser Trp Pro Gln Arg Leu Asp Ile Leu Leu  
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 325 330 335  
 Ile His Gly Asp Ile Lys Ser Ser Asn Val Leu Leu Asp Glu Arg Leu  
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 Thr Pro Lys Leu Gly Asp Phe Gly Leu Ala Arg Phe Ser Arg Phe Ala  
 355 360 365  
 Gly Ser Ser Pro Ser Gln Ser Ser Met Val Ala Arg Thr Gln Thr Val  
 370 375 380

Arg Gly Thr Leu Ala Tyr Leu Pro Glu Glu Tyr Ile Lys Thr Gly Arg  
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 405 410 415  
 Thr Leu Ala Gly Gln Arg Ala Val Lys Thr His Gly Ala Arg Thr Lys  
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 465 470 475 480  
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 485 490 495  
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 500 505 510  
 Gln Val Tyr Glu Arg Leu Glu Lys Leu Gln Ala Val Val Ala Gly Val  
 515 520 525  
 Pro Gly His Leu Glu Ala Ala Ser Cys Ile Pro Pro Ser Pro Gln Glu  
 530 535 540  
 Asn Ser Tyr Val Ser Ser Thr Gly Arg Ala His Ser Gly Ala Ala Pro  
 545 550 555 560  
 Trp Gln Pro Leu Ala Ala Pro Ser Gly Ala Ser Ala Gln Ala Ala Glu  
 565 570 575  
 Gln Leu Gln Arg Gly Pro Asn Gln Pro Val Glu Ser Asp Glu Ser Leu  
 580 585 590  
 Gly Gly Leu Ser Ala Ala Leu Arg Ser Trp His Leu Thr Pro Ser Cys  
 595 600 605  
 Pro Leu Asp Pro Ala Pro Leu Arg Glu Ala Gly Cys Pro Gln Gly Asp  
 610 615 620  
 Thr Ala Gly Glu Ser Ser Trp Gly Ser Gly Pro Gly Ser Arg Pro Thr  
 625 630 635 640  
 Ala Val Glu Gly Leu Ala Leu Gly Ser Ser Ala Ser Ser Ser Ser Glu  
 645 650 655  
 Pro Pro Gln Ile Ile Ile Asn Pro Ala Arg Gln Lys Met Val Gln Lys  
 660 665 670  
 Leu Ala Leu Tyr Glu Asp Gly Ala Leu Asp Ser Leu Gln Leu Leu Ser  
 675 680 685  
 Ser Ser Ser Leu Pro Gly Leu Gly Leu Glu Gln Asp Arg Gln Gly Pro  
 690 695 700  
 Glu Glu Ser Asp Glu Phe Gln Ser  
 705 710

WHAT IS CLAIMED IS:

1. An isolated human Interleukin-1 Receptor-Associated Protein Kinase (IRAK) which migrates under SDS-polyacrylamide gel electrophoresis at an apparent molecular weight of approximately 100 kD.
2. An isolated human Interleukin-1 Receptor-Associated Protein Kinase (IRAK) comprising a kinase domain having the amino acid sequence of SEQUENCE ID NO:2, residues 212-523.
3. An isolated nucleic acid encoding a human Interleukin-1 Receptor-Associated Protein Kinase (IRAK) kinase domain according to claim 2.
4. An isolated first nucleic acid comprising SEQUENCE ID NO:1 or capable of specifically hybridizing with a second nucleic acid having the sequence defined by SEQUENCE ID NO:1 and remaining bound at a reduced final wash stringency of 0% formamide in 0.9 M saline/0.09 M sodium citrate (SSC) buffer at a temperature of 42°C.
5. An isolated nucleic acid having the sequence defined by SEQUENCE ID NO:1 or a fragment thereof capable of hybridizing with a nucleic acid having the sequence defined by SEQUENCE ID NO:1 under stringency conditions defined by a hybridization buffer comprising 20% formamide in 0.9 M saline/0.09 M sodium citrate (SSC) buffer at a temperature of 42°C and remaining bound when subject to washing at 42°C with 2 X SSC buffer.
6. A method of identifying lead compounds for a pharmacological agent useful in the diagnosis or treatment of disease associated with Interleukin-1 signal transduction, said method comprising the steps of:
  - forming a mixture comprising:
    - a human IRAK according to claim 2,

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a natural intracellular IRAK binding target, wherein said binding target is capable of specifically binding said IRAK, and

a candidate pharmacological agent;

5 incubating said mixture under conditions whereby, but for the presence of said candidate pharmacological agent, said IRAK selectively binds said binding target;

detecting the presence or absence of specific binding of said IRAK to said binding target,

10 wherein the absence of said selective binding indicates that said candidate pharmacological agent is a lead compound for a pharmacological agent capable of disrupting IRAK-dependent signal transduction.

7. A method according to claim 6, wherein said IRAK  
15 binding target comprises an intracellular fragment of the Interleukin-1 receptor.

8. A method of identifying lead compounds for a pharmacological agent useful in the diagnosis or treatment of disease associated with Interleukin-1 Receptor Associated  
20 Protein Kinase activity, said method comprising the steps of:

forming a mixture comprising:

a human IRAK according to claim 2,

a natural intracellular IRAK substrate, wherein  
25 said IRAK is capable of specifically phosphorylating said substrate, and

a candidate pharmacological agent;

incubating said mixture under conditions whereby, but for the presence of said candidate pharmacological agent,  
30 said IRAK selectively phosphorylates said substrate;

detecting the presence or absence of specific phosphorylation of said substrate by said IRAK,

wherein the absence of said phosphorylation indicates that said candidate pharmacological agent is a lead compound  
35 for a pharmacological agent capable of disrupting IRAK activity.

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9. A method according to claim 8 wherein said IRAK substrate is said IRAK.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US96/09193

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) : Please See Extra Sheet.

US CL : 530/300; 536/22.1, 24.3; 435/6, 7.1

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 530/300; 536/22.1, 24.3; 435/6, 7.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

MEDLINE, USPATFULL, WPIDS

search terms: IL-1, receptor, protein kinase

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	LIU et al. Renaturation and tumor necrosis factor-alpha stimulation of a 97kDa ceramide-activated protein kinase. The Journal of Biological Chemistry. 28 January 1994, Vol. 269, No. 4, pages 3047-3052, see the entire document.	1
X, P ----- Y, P	CAO et al. IRAK: A kinase associated with the interleukin-1 receptor. Science. 23 February 1996, Vol. 271, pages 1128-1131, see the entire document.	1-5 ----- 6-9
Y, P ----- X, P	CROSTON et al. NF-kB activation by Interleukin-1 (IL-1) requires an IL-1 receptor-associated protein kinase activity. The Journal of Biological Chemistry. 14 July 1995, Vol. 270, No. 28, pages 16514-16517, see the entire document.	1-5 ----- 6-9

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	*T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*A* document defining the general state of the art which is not considered to be part of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
*E* earlier document published on or after the international filing date	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Z* document member of the same patent family
*O* document referring to an oral disclosure, use, exhibition or other means	
*P* document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

20 AUGUST 1996

Date of mailing of the international search report

18 SEP 1996

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## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US96/09193

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	THE NEW ENGLAND BIOLABS CATALOG. 1993/1994 Edition, page 97, see Primer No. 1325.	4, 5
Y	MARTIN et al. Interleukin-1-induced activation of a protein kinase co-precipitating with the type I interleukin-1 receptor in T cells. European Journal of Immunology. July 1994, Vol. 24, pages 1566-1571, see the entire document.	1-9

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US96/09193

## A. CLASSIFICATION OF SUBJECT MATTER:

IPC (6):

A61K 38/00, C07K 2/00, 4/00, 5/00, 7/00, 14/00, 16/00, 17/00; C07H 19/00, 21/00, 21/04; C12Q 1/68; G01N 33/53